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The China Productivity Project: Results and Conclusions

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ABSTRACT Experiments were conducted to determine what factors cause variation in individual work output (economic productivity). Forty-five young male Chinese cycle haulers from Beijing were assessed for physiological work capacity, size and body composition, health, nutritional status, cold resistance, household social environment, and motivation. Experiments were conducted in the laboratory as well as under actual working conditions; ethnographic observations were made in the household and on the job during the Beijing winter of 1992. Overall work motivation correlated to actual monthly distance/load measures of productivity the most strongly ($r = 0.518$), followed by physiological capacity estimated by heart rate:speed ratio during field experiments ($r = -0.473$). Alcohol consumption (a negative factor), household health, and carbohydrate intake were all moderate predictors. Maximum oxygen uptake showed lower correlation ($r = 0.261$), and among anthropometric values only relatively long lower legs were predictive ($r = 0.298$). Since many of these variable categories were relatively independent of each other, multiple regression analysis showed that together they explained 61.6% of the work output variance. Simultaneous prediction by FASEM (LISREL) is also very strong. Am J Phys Anthropol 103:295–313, 1997.

This paper has the following objective. We examine how the amount of work done by Chinese laborers is predicted by a range of behavioral, physiological, and environmental variables. Our analytic approach uses simple and multiple variable statistics and structural equation modeling. The dependent variable, documented work performance (economic productivity), is related to single measures as well as to statistically derived factors acting as independent variables. We assume these correlations reflect causal patterns, but they may be more cautiously construed to be merely predictive.

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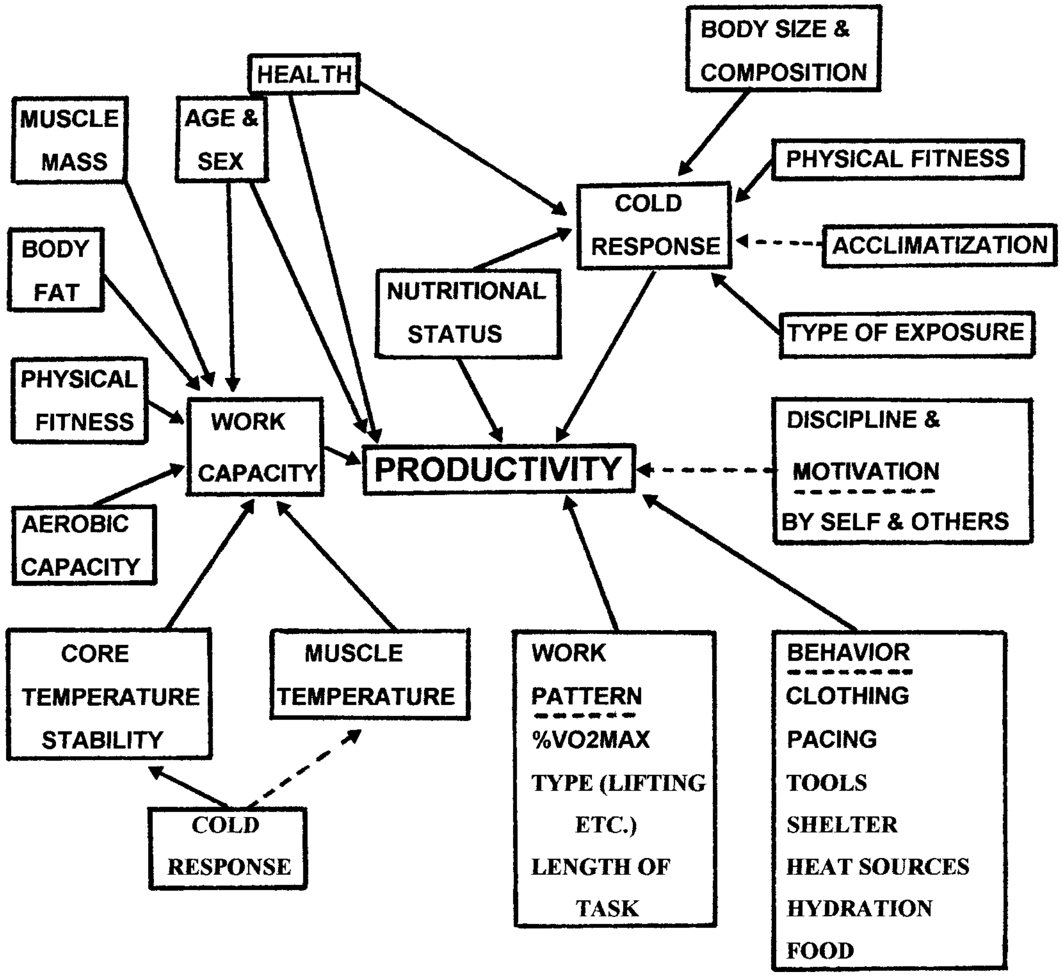

Fig. 1. This is the basic model used to structure this investigation. Productivity (mean daily and mean monthly pay) is the dependent variable category, and arrows show causation by categories of independent variables. For simplicity, not all of the potential interactions between variables are shown (Steegmann et al., 1995a).

tors from the United States of America and the People's Republic of China. Our focus was production by individual workers. However, work output is hard to quantify unless specific products, or the time and energy required to produce, can be tied to specific workers. These connections may be unclear where hourly wages are paid for work or where work is done by teams. Consequently, we selected an occupation that has an important economic function in Beijing and pays workers by the unit of work completed. Cycle haulers do much of the carting of loads up to 500 kg on three-wheeled, human-powered platform cycles. They are paid by the load weight and the distance it is hauled, and meticulous pay records of each trip are kept by management. Pay is a strong direct measure of work.

A biocultural model and causal assumptions

This research was structured with the aid of a biocultural model, presented in Steegmann et al., 1995a (Fig. 1). The model was influenced by work physiologists Åstrand and Rodahl (1986) and by anthropological investigations reported in Damon (1975)

and Collins and Roberts (1988). The necessity for using multidisciplinary, holistic research strategies is expressed in all of these sources.

The model's logic is that work output is driven in part by a complex of conditions ranging from natural to social. The directions of assumed productivity causation are shown by arrows. Past research, reviewed by Steegmann et al. (1995a), indicated that all of the independent variables shown would be expected to affect work outcomes. It was anticipated that multivariate analysis would eventually simplify this picture due to interactions between independent variables. For instance, we would expect that high aerobic capacity would reduce the perceived difficulty of hauling a standard load and consequently increase a worker's motivation to produce more. However, most of the expected interactions are not shown in Figure 1 in the interest of clarity. The model will be more predictive if the categories of independent variables are unrelated to each other. While this was an expectation during model construction, it will be tested empirically later in the paper.

MATERIALS AND METHODS

An analysis of hauler production measures and descriptions of techniques used in testing the biocultural model are found in Hewner and Sun (1995) and Steegmann et al. (1995a,b). Laboratory procedures were done at the Department of Work Physiology, Institute of Occupational Medicine, Chinese Academy of Preventive Medicine (Beijing), from January through March 1992. Field tests took place on a course laid out in streets near the Institute, and each worker was also visited in his residence. Subject volunteers came from the Administrative Station, Chun Wen District for Manpower Transportation, Tien Tan Branch. The Institute is situated in south central Beijing west of the Temple of Heaven complex.

Sample

Subjects in this study were 45 males between 20 and 42 years old, all paid volunteers who were working at the cycle hauling trade. Each had been hauling long enough to accrue pay records for the 2 months preceding testing (November–December 1991), and 40 out of the 45 men also had pay records for June–July 1991. Cooperation between the subjects and the research team was excellent.

The Tien Tan work unit (company) of south central Beijing consisted of a management staff that solicited work and handled assignments and pay and a total of 64 workers who fit our criteria. They had to be between 20 and 35 years old and have had enough time on the job to be adjusted to the physical demands of the trade. We later adjusted the acceptable age upward to 42 years in order to get an adequate sample. Four of the 64 eligible workers chose not to participate, and the remaining 60 were recruited as subjects. However, because we were able to complete controlled field experiments on only 45 workers, and because results from those experiments looked like an important type of data, we accepted a smaller sample. Of the original 60 men, lack of field data and other occasional deficiencies in the data sets were apparently random losses (one without blood pressure readings, another who was working with his wife, etc.). As far as we could determine, this hauling unit carried the same kinds of loads the same distances on the same kinds of cycles as other Beijing haulers.

Measurement issues

The purpose of this section is to describe how we estimate general predictors shown in the model through specific measures. There are two categories of measurements. Most are interval variables such as height or daily carbohydrate consumption. However, there are also important pieces of information that cannot be measured in centimeters or calories. In most cases these are qualitative judgments expressed as five-point Likert scales. Renis Likert introduced this method in 1932 to quantify attitudes, and it is now a standard tool in behavioral research (Bernard, 1994). With job satisfaction as an example, the five responses would be 1) dislike job strongly, 2) dislike job moderately, 3) neutral about job, 4) like job moderately, and 5) like job strongly. In other words, this is a quantified estimate of subjective feelings. In the present investigation,

Likert scales were assigned in two ways: either the informant made the choice, or the investigator made the choice based on a series of questions and observations during interviews. For instance, individual health was estimated by the subject as well as by the Chinese physician investigator following a physical examination and health inquiry. Household health was a composite mean of Likert scales for each household member.

Amongst the most complex rating estimates was motivation. First, the boss of the work unit was asked to identify a set of characteristics that contribute to being a good worker. These include cooperation with others, ability to follow instructions, ability with customers, resistance to fatigue, self-discipline, and so on. While the boss assigned a five-point scale to some of these traits separately, he also gave an overall score of general worker contribution to the work unit. During the interview the research team solicited the worker's own Likert score assessment on how well he liked the job. Finally, the physician/ethnographer team assigned a general score based on interviews and a home visit. While we refer to this last estimate as part of the overall motivation/ability assessment (Table 1) and specifically as the ethnographic estimate (overall) in Table 2, it is probably the most broad-based Likert scale that describes general worker ability (see Hewner and Sun, 1995). It was expected to interact statistically with the boss's scores, and these "insider" and "outsider" estimates are employed as alternative measures of the same property.

Likert scales are widely employed in statistical tests (Borgatta and Bohrnstedt, 1981). However, their usefulness also carries a cautionary note. These single judgments are based on complex observations so that the scores may correlate with a variety of other measures. That will be considered as the analysis proceeds, but the usefulness of these scores is shown in the following result from this study. Hewner and Sun's rating of overall motivation of the haulers predicted their mean monthly pay more strongly ($r = .518$) than did any other single measure, physiological or otherwise. This score was assigned independently of knowledge of each worker's productive performance.

Rating the workers for alcohol use was an interesting challenge. After the data were collected and reviewed, we developed an alcohol score with four ordinal levels. Assigning a level raised reliability questions because some of the reporting sounded a little vague. Also, smaller quantities of beer may have been omitted from reports if they were part of a meal. However, "white liquor" (a distilled spirit) is not considered food and is the focus of a good bit of ritualized social drinking. Higher alcohol intake tended to be largely white liquor or both beer and liquor. By the end of our contact with the workers, we had a fairly good picture of which men had higher levels of alcohol intake and which used none.

Maximum oxygen uptake is used within exercise physiology as one of the fundamental measures of work capacity. There is no question that there is great individual variation in ability to deliver oxygen to tissue and in the amount of muscle mass available to do physical work. However, the accuracy of the $\dot{V}O_2max$ measurement depends on whether the subject actually delivers a maximum performance, given that the test assumes exercising to exhaustion. During the test, the subject may give the appearance of great exertion and indicate he is at peak when he is actually considerably below maximum. In a small sample such as this, two or three false maxima can have big effects on correlation coefficients, particularly if "true" correlations with variables such as pay are already low or at the borderline of statistical significance. We are candid in noting that these false scores could decrease the relative importance of physiological capacity in explaining productivity.

Dependent variables

Since haulers were paid according to tariff tables set by the weight of the load (kilograms) and the distance it was carried (kilometers), pay is an accurate measure of work done. We chose two different pay measures because each has potentially different causes of variation. Mean monthly pay (MMP1 in Steegmann et al. [1995a]) is the total pay earned by the worker divided by the number

of months worked and serves as our primary measure of productivity. Months when there was less than 100 yuan income were eliminated from calculation. This measure is a realistic estimate of income, and it reflects work capacity as well as the numerous social and environmental factors that cause income to fluctuate. Mean daily pay (total pay divided by the number of actual work days) is an estimate of what someone earns when actually working. We predicted that a worker with less physical capacity but strong motivation should rank higher in mean monthly pay. Someone who is a productive worker but for various reasons hauls fewer days per month should rank higher in daily pay but lower in monthly.

Both measures have high face validity (Bernard, 1994), and their reliability is indicated by careful administrative record keeping and knowledge of distances between different loading and unloading sites in Beijing. Management procedures were observed during ethnographic visits to the work unit office and were evident in the carefully documented pay records. During this phase of the field investigation we also concluded that work is generally available on any day the worker appears on time and that the work available is equitably distributed. However, the worker may choose to do more or less hauling on any given day or may choose to take a day off. This latitude is what contrasts to the situation of factory workers, for example, and is also what makes this occupation ideal for individual productivity study.

Finally, a mean monthly productivity measure was chosen in preference to measures of total pay because it adjusts for variable periods worked. That is, a hauler who worked 4 months could be compared directly to someone who had recently joined the organization and had only accrued 3 months of pay records. Steegmann et al. (1995a) offer detailed discussion of productivity measurement.

Independent variables

Table 1 presents descriptions and technique references for independent variables used in the analysis. Descriptive statistics of each variable are given in Table 2, organized under categories determined by the model (Fig. 1). In categories where a range of variables is employed, we attempt to insure that useful information is considered. For instance, physical size is often measured as height, weight, and body mass index. However, some variance in cycle hauler performance might also be explained by relatively longer legs, greater frame size (elbow breadth), less body fat, and so on. Likewise, it is hard to predict a priori what measure of health or motivation is most efficient in this setting, so a range of measures is employed within some model categories.

Maximum oxygen uptake ($\dot{V}O_2max$) was determined using cycle ergometry and indirect calorimetry by the Douglas Bag technique of respiratory gas collection. On a Monark Ergomedic 829E ergometer, the pace was set at 60 rpm, and subjects were started at a practice level of 50 watts resistance. This level was continued until it was clear that the task was understood and that the mask (used for gas collection) and other equipment were functioning properly. The first gas collection level was 75 watts, and the workload was increased by 35 watt increments, with gas collection at each new plateau. Since preliminary testing showed that many subjects could not keep the pace after the 215 to 250 watts increase, steps were set at 15 watts after the 215 watt level. The work load increased every 3 min without rest until the worker was exhausted. Gas samples were assessed immediately by forcing gas from the collection bag through a flow meter and Beckman carbon dioxide and oxygen analyzers. Gas was corrected to standard temperature and pressure. Heart rates were recorded using Monark chest strap sensors, and body temperatures (rectal, finger, back) were measured by Yellow Springs digital telethermometers. Tests were run in an environmental chamber kept at 3°C ambient with a frontal airflow of 1.5 m/s. This simulated expected winter outdoor work conditions in Beijing.

Chinese physicians and health technicians conducted health examinations, including a general health history, days missed due to illness (2 week recall), blood pressure, electrocardiogram, hemoglobin (HemoQue photometer), hematocrit, alcohol and to-

TABLE 1. Names and descriptions of measurements used in this project, with references

Maximum oxygen uptake ($\dot{V}O_2max$)	Determined by indirect calorimetry using the Douglas Bag technique, with mechanical flow meter and O_2/CO_2 analyzers, STPD; analyzers calibrated before each set of tests; men exercised on a Monark cycle ergometer (829E) advancing by 35 watt increments, starting at 75 w and going to exhaustion; gas samples drawn after performance stabilized during the last minute of each 3 min step; ambient conditions: 3°C, 1.5 m/s frontal air movement (Consolazio et al., 1963; McArdle et al., 1991; Steegmann et al., 1995a)
Maximum heart rate	The highest sustained rate reached at peak performance during the maximum oxygen uptake tests; determined using the chest strap sensor supplied with the Monark ergometer
Boss's estimate, overall contribution to the unit	A five-point rating that reflects the worker's general effectiveness; includes judgments about taking orders, ability to get along with customers and fellow workers, dependability, endurance, and so on; a rating of 1 represents a marginal employee, although presence in the work unit shows the person can at least do the work; those clearly superior in performance and human relations are rated 5
Boss's estimate, physical work capacity	A five-point rating of the hauler's physical capacity for the strenuous work of hauling; a rating of 1 indicates someone who has the lowest capacity to do hauling and may have to be given lighter loads; while 5 indicates someone who can haul the heaviest loads long distances multiple times per day; since these subjects are all working as haulers, however, even a person rated 1 passes minimal physical ability expectations; scoring discussed further in Bernard (1994), Hewner and Sun (1995), and the text
Heart rate:speed ratio	The mean heart rate/min during the 14.18 km outdoor experiment divided by the mean speed during the experiment; assumption that the lower the heart rate at any speed, the higher the work capacity; Polar Vantage XL recording heart rate monitor (a chest strap sensor-transmitter and a wrist receiver-recorder system) was used (Steegmann et al., 1995b)
Anthropometrics	Include height, sitting height, and lower leg length (anthropometer), weight (beam balance), elbow breadth (sliding caliper) and skinfolds (Lange calipers) and employed standard techniques (Lohman et al., 1988); BMI = wt kg/ht m^2; relative sitting height = sitting height/height; relative lower leg length = lower leg length/height − sitting height; fat-free mass, see Lohman (1981); calf muscle area, cm^2, see Frisancho (1990); for calf muscle area, maximum calf circumference determined by insertion tape, and a medial, vertical skinfold was taken using Lange calipers at the same level as the maximum circumference
Age	Calculated in decimal years as the interview date minus the birth date
Health	Ratings of haulers, on five-point scales, were assigned by a Chinese physician after a health interview and physical examination; the hauler also rated his own health on a five point scale; his rating of the health of each household member was summed and averaged for the household health score
Days ill	The number of days during the last 14 days that illness prevented going to work
Smoking	The number of packs of cigarettes smoked per day; ranged from 0–4, so five levels of cigarette use were estimated by this indicator, from no use to four packs per day
Alcohol use	Estimated by a question on consumption during the health examination; reliability was checked using alcohol consumption reports in three 24 h food intake recalls; if subjects said they used no alcohol and reported none on the 24 h recalls, they were rated 0; those given a 1 made light daily use of alcohol, usually beer equivalent in content to less than 50 ml absolute ethanol; Moderate users, rated 2, consumed the equivalent of 50–100 ml absolute, and those rated 3 drank the equivalent of more than 100 ml absolute; Even those rated 3 were regular, active haulers
Hemoglobin	Estimated by blood drawn from the earlobe; after puncture by lancet, the first drop of blood is swabbed away and a sample drawn into a microcuvette; reading made in a HemoQue photo colorometer calibrated against the standard supplied and checked periodically against blood from the clinical team
Blood pressure	Taken during the medical examination with the subject seated and resting, arm at heart level, using a mercury sphygmomanometer
Mean daily and monthly pay	Taken from pay records covering June/July and November/December 1991, immediately prior to the experiments reported here (January/March 1992); pay is determined by tariffs established for distance and weight of load; record keeping by the company was meticulous and included every load hauled (for details see Steegmann et al., 1995a)
Mean daily protein, fat, and carbohydrate intake	Determined from information in three 24 h food recalls using the food composition tables for Asia (FAO, 1972)
Thermal response to cold	Determined by Yellow Springs Instrument digital resistance thermometer; Rectal core temperatures taken immediately before and just after the maximum oxygen uptake test (ambient is 3°C with frontal breeze of 1.5 m/sec)

TABLE 1. (continued)

Ethnographer's overall motivation/ability	Assigned as a five-point score by the medical anthropologist (S.H.) and the Chinese physician (W.S.) working together; estimates the hauler's overall motivation to work as judged after one short and one long interview plus a visit to the worker's residence; score based on attitude toward the job, responsiveness to authority, social interactions at home and at the Institute, and a sense of how well integrated and managed the worker's life was (other components covered in the text); a 1 rating assigned to workers who lived alone in messy conditions and appeared to be without social support or ambition to earn; 5 rating assigned to someone who seemed focused, disciplined, well integrated with a social net, and in optimum command of life
Worker education	Number of school years completed
Like job?	Worker picked a number on a five-point scale to indicate how well he liked his work as a hauler
Borg scale	Used in physiological studies to get the subject's own estimation of how stressful the test was; the old version, a fifteen point score from extremely light exertion up to extremely hard (at the very limit of toleration) used here; completed by haulers following the oxygen uptake test and after the field test (Borg 1982)
Mean speed (field experiment)	Speed maintained by the hauler during the experiment, as calculated from the time required to complete the 14.18 km course, and stated as kilometers per hour; one index of voluntary work output
Heart rate variation (field experiment)	Standard deviation of heart rate during the field experiment; indicates the amount the hauler varies his pace; a low value implies better work toleration, less strain, and perhaps more discipline
Heart rate as a % of maximum (field experiment)	Calculated as the mean heart rate during the exercise divided by the maximum heart rate attained at the peak of the maximum oxygen uptake test; a common index of the portion of physiological capacity that is voluntarily taxed during work (Åstrand and Rodahl, 1986)

bacco use, and a physical examination. Each worker was also given a general health score and was asked for a health self-assessment, both on five-point scales. Health information was collected to eliminate anyone at risk from our experiments as well as for its value as research data.

While oxygen uptake tests estimate work capacity, they do not indicate how that capacity is used in the workplace. For that, we conducted field experiments on each worker hauling a load through the streets. The task matched exactly what the haulers do on a daily basis. They moved the research cycle (machine, two observers, and ballast weighing 481 kg) over a 14.18 km course. While the cycle's weight and course were constant, weather conditions and traffic varied, and each worker set his own clothing, food intake, and pace. As in the oxygen testing, heart rates and body temperatures were monitored. The two observers, riding as part of the load, also noted work behavior. More detail is given in Steegmann et al. (1995b).

Each worker's social environment and personal work-enhancing behaviors were assessed during a long interview held in privacy at the Institute. It evaluated the worker's status on material, social, and attitudinal variables, some interval, some ordinal, and some nominal. This information was supplemented and verified during a subsequent visit to the worker's residence. While the home visit was a public event in which the hauler's supervisor was present, it nevertheless allowed investigators a unique chance to judge the quality of social conditions at home. From these observations as well as from watching peer behavior of workers and from extended discussions with managers as to what defined a good worker, we constructed motivation/behavior scores. Further details are in Hewner and Sun (1995), in the "Measurement Issues" section above, and in Tables 1 and 2.

ANALYTIC APPROACH

The purpose of this analysis is to test the original model for its power to predict work output. We examine the data using three approaches, each offering some insights not revealed by the others.

First, basic data descriptions include both distributions of the data as well as their simple product moment correlations to the two dependent variables, mean monthly and mean daily pay. This allows us to judge whether measures within each original model category are of predictive value and whether the model categories themselves

TABLE 2. Independent variables[1] are presented according to categories in the original model

	Min	Max	Mean	SD	Correlation: Monthly pay	Correlation: Daily pay
Aerobic capacity						
Boss's estimate, physical work capacity	2.0	5.0	3.84	0.88	.225	.280
$\dot{V}O_2$max, l/m	2.24	4.37	3.10	0.41	.261	.203
$\dot{V}O_2$max, ml/kg/m	38.62	69.50	49.55	6.25	.101	.039
Maximum heart rate	163.0	207.0	186.9	11.14	−.252	−.167
Heart rate: speed (N = 41)	11.68	24.34	15.38	2.06	−.473**	−.453**
Physical traits						
Height, cm	160.8	183.4	169.5	4.99	−.008	.102
Weight, kg	51.5	83.5	62.96	7.54	.176	.179
Elbow breadth, mm	63.0	75.0	68.4	3.05	.142	.242
Sitting height, cm	86.8	101.2	92.8	2.83	−.184	−.140
Body mass index	18.78	29.6	21.88	2.16	.213	.152
Subscapular skinfold, mm	6.5	34.5	10.97	5.10	.112	.120
Triceps skinfold, mm	4.5	15.0	7.01	2.68	.094	.073
Relative sitting height, %	52.2	56.99	54.76	1.15	−.248	−.340*
Lean body mass, kg	48.47	77.98	58.32	6.59	.180	.187
Relative lower leg length, %	49.36	61.89	54.89	2.45	.298*	.372**
Calf muscle area, cm^2	66.73	118.3	93.28	11.49	.000	.126
Age						
Years	20.10	42.84	27.54	5.09	.055	−.066
Health						
Self-rated	3.0	5.0	3.36	0.53	−.100	.019
Physician's estimate	3.0	5.0	3.60	0.58	.288	.226
Household, mean	2.0	4.0	3.38	0.61	.421**	.347*
Days ill (2 weeks)	0.0	14.0	1.56	3.53	−.114	−.110
Smoking, packs/day	0.0	4.0	1.82	1.32	−.226	−.120
Alcohol use	0.0	3.0	1.09	1.02	−.469**	−.439**
Hemoglobin, g/dl	14.3	20.0	17.26	1.27	−.025	.028
Systolic blood pressure	110.0	140.0	122.4	9.19	.256	.200
Diastolic blood pressure	61.0	90.0	76.8	3.53	.111	.044
Nutrition						
$\bar{X}$ daily carbohydrates, g	91.4	475.9	248.9	91.46	.347*	.187
$\bar{X}$ daily protein, g	35.5	162.1	81.3	30.19	.278	.199
$\bar{X}$ daily Kcal	1269	3602	2457	623	.188	.147
Cold response						
Core temperature change, °C (O_2 uptake test)	0.40	1.40	0.87	0.22	.049	−.124
Motivation/behavior						
Ethnographic estimate (overall)	1.0	5.0	3.28	0.96	.518**	.396**
Boss's estimate (overall)	2.0	5.0	3.49	0.69	.296*	.321*
Boss's estimate, worker cooperation	1.0	5.0	3.24	0.80	.196	.276
Boss's estimate, general contribution	2.0	5.0	3.71	0.87	.449**	.332*
Like job?	2.0	5.0	3.51	0.76	.304*	.311*
Hauler's education	3.0	11.0	7.58	1.74	.238	.102
Borg (field, N = 41)	9.0	17.0	12.85	1.37	.140	−.012
Borg (O_2 test, N = 41)	12.0	19.0	14.98	1.53	−.295	−.231
Work pattern						
$\bar{X}$ speed (field, N = 41)	6.68	13.3	10.39	1.42	.361*	.336*
Heart rate SD (field, N = 41)	4.02	15.79	9.38	2.69	.074	−.006
Heart rate %max (field, N = 41)	61.59	97.69	84.16	7.95	−.031	−.127
Household/social/demographic						
People in family	5.0	8.0	7.58	0.81	−.004	−.100
Number of income earners	1.0	4.0	1.69	0.73	−.005	−.038
Dependency ratio, persons/worker	1.0	5.0	2.0	0.92	.264	.244
Household assets	1.0	4.0	2.89	0.86	.232	.007
Married	0.0	1.0	0.82	0.39	—	—
Owns house	0.0	1.0	0.64	0.48	—	—
Per capita floor area, m^2	1.50	27.43	12.54	6.62	−.129	−.142
% chores by worker	15	100	48.5	22.65	−.219	−.219
Productivity (dependent variables)						
$\bar{X}$ monthly pay, yuan	165.3	862.3	539.9	183.9	1.0	.795**
$\bar{X}$ daily pay, yuan	20.7	45.4	31.4	5.55	.795**	1.0

[1] Descriptives include minimum, maximum, mean, and standard deviation. The last two columns show product moment correlations to the two dependent measures of productivity, mean monthly pay and mean daily pay. Statistical significance levels of the correlation coefficients are <.05 (*) and <.01 (**) in two-tailed tests. Sample is 45 unless otherwise indicated.

TABLE 3. Outcome of a backward stepwise multiple regression between mean monthly pay and independent variables[1] representing categories in the theoretical model

Dependent variable	Beta	T	Sig.	Correlations: Boss's estimate	Household health	Daily carbo-hydrates	Systolic blood pressure	Physician's health estimate	Mean monthly pay
Alcohol use	−.394	−4.014	.001	−.073	−.164	−.146	−.054	−.054	.469**
Boss's estimate of contribution	.342	3.411	.002	—	.124	−.050	.305*	.179	.449**
Household health	.279	2.856	.007	—	—	−.012	.021	.179	.421**
Daily carbohydrates	.274	2.769	.009	—	—	—	−.075	.291	.347*
Systolic blood pressure	.250	2.486	.017	—	—	—	—	−.063	.256
Physician's health estimate	.187	1.864	.070	—	—	—	—	—	.288

$R = .818$; $R^2 = .669$; adjusted $R^2 = .616$; $F = 12.772$; significance = .0009
F is the ANOVA value for overall fit of data to the multiple regression equation

Variables dropped out	Correlations to mean monthly pay
Ethnographer overall motivation	.518**
Relative sitting height	−.248
Weight	.176
$\dot{V}O_2$max	.261

[1] The ten independent variables submitted include ethnographer's estimation of overall motivation, boss's scoring of contribution to the work unit, $\dot{V}O_2$max, household health score, physician's rating of worker's health, systolic blood pressure, alcohol use, carbohydrate intake, body weight, and relative sitting height. The right side of the table gives simple correlations between the variables that entered and remained in the equation. Below are values that dropped out and overall values reflecting fit of the equation to the data. N = 45. Significance levels are $P < .05$ (*) and $P < .01$ (**).

TABLE 4. Multiple regression[1] similar to that in Table 3, except that nutrition and health variables were not submitted

Independent variable	Beta	T	Significance	Correlations to mean monthly pay: Ethnographer's estimate	Systolic blood pressure	Mean monthly pay
Alcohol use	−.410	−3.237	.002	−.317*	.181	−.461**
Ethnographer's overall motivation	.347	2.760	.009	—	.145	.518**
Systolic blood pressure	.280	2.310	.026	—	—	.256

$R = .666$; $R^2 = .444$; adjusted $R^2 = .403$; $F = 10.908$; significance = .0009

Variables dropped out	Corr. to $\overline{X}$ mo pay
$\dot{V}O_2$max	.261
Boss's estimate, overall	.449**
Relative sitting height	−.248
Weight	.176

[1] This is additional analysis to adjust for the possibility that nutrition and health are not independent variables but rather effects of productivity. More detail is given in the text. Other conditions are as in Table 3. N = 45. Significance levels are $P < .05$* and $P < .01$**.

were well conceived. In one important area, physiological work capacity, the simple correlations are uniquely useful. Heart rate: speed ratio (from the controlled field experiments) was dropped from the first two multiple regression analyses (Tables 3, 4) because its use would reduce the entire sample to only 41. However, this ratio is clearly a much stronger measure than $\dot{V}O_2$max in predicting productivity (see Table 2). Consequently, an additional multiple regression was run (Table 5) using the heart rate:speed variable instead of $\dot{V}O_2$max and the smaller sample of 41.

Multiple regression assumes that independent variables are not multicollinear (Pedhazur, 1982), and those chosen in specific tests reported below are not. Variables should also be homoscedastic. We examined this in our key variables and found that alcohol use was heteroscedastic with productivity due to higher variation in productivity among those who reported no alcohol use. However, when alcohol use was converted to a dichotomous value (use/no use) and entered into the regression as a dummy variable, the results were very much the same as previous outcomes using the four-point alcohol variable.

TABLE 5. Multiple regression[1] employing the variables used in Table 3, except that heart rate for speed is substituted for $\dot{V}O_2max$

				Correlations				
Independent variable	Beta	T	Sig	Boss's estimate	Daily carbo-hydrates	Household health	Systolic blood pressure	Mean monthly pay
Alcohol use	−.375	−3.483	.001	−.095	−.152	−.146	.232	−.447**
Boss's est., con.	.373	3.454	.001	—	−.099	.139	.285*	.496**
Daily carbohydrates	.348	3.304	.002	—	—	−.065	−.234	.284*
HH health	.317	3.059	.004	—	—	—	.035	.411**
Systolic blood pressure	.270	2.415	.021	—	—	—	—	.219

$R = .800$; $R^2 = .641$; adjusted $R^2 = .598$; $F = 12.477$; significance = .0009

Variables dropped out	Corr. $\overline{X}$ mo pay
Relative sitting height	−.164
Weight	.215
Ethnographer's overall estimate	.520**
Heart rate:speed	−.437**

[1] This is additional analysis was executed because heart rate:speed as a measure of physiological capacity predicted mean monthly pay better than did $\dot{V}O_2max$ when considering bivariate correlations. However, this sample was reduced to 41 due to missing data. Other conditions are as in Table 3. Significance levels are $P < .05$* and $P < .01$**.

Because of this picture and the relatively low level of heteroscedasticity, we will use the alcohol variable, reservations noted. Our sense of the overall suitability of this data set for the statistics employed is that it matches general usage in human biology field studies. "It has been demonstrated that regression analysis is generally robust in the presence of departures from assumptions . . ." (Pedhazur, 1982:34).

The data set is also subjected to structural equation model testing (usually referred to FASEM or LISREL). In this approach, the investigator proposes a structure of causal interactions between major theoretical constructs, each measured by multiple indicator variables. Path coefficients and other parameters for the proposed model are estimated based on covariance structure of the measured data. Overall fit of measured data to a model is assessed using a chi-square statistic as well as a variety of more robust goodness-of-fit indices (Byrne, 1994). In both multiple regression and FASEM analysis, poor model design or relationships between independent variables weaken explanatory power.

RESULTS

Values in Table 2 show that measured variables exhibit enough variation to be of potential use as statistical predictors. Since this is a sample of self-selected workers doing hard physical labor, and since not all of the variables listed have been measured in previous studies, the issue of adequate variance is important. The coefficient of variation (standard deviation as % of mean) is a simple, standardized measure of variation. Physiological measures show expected variation ($\dot{V}O_2max$,l/m = 13.3%; systolic blood pressure = 8.5%), while five-point scale ratings tend to be higher (self-rated health = 16.0%; boss's estimate of worker contribution = 23.7%).

The overall picture conveyed by the sample means is of a group of men just over a centimeter taller than the fiftieth percentile value of Chinese standards for height and 4 kg over for weight. The haulers showed mean height of 169.5 cm, compared to 168.3 national young adult mean, and 63.0 kg weight, compared to 59.0 kg national young adult mean (Human Dimensions of Chinese Adults, 1988). This may be no more than an expression of Bergmann's rule in China. Likewise, the hauler maximum oxygen uptake of 3.1 l/m is equivalent to Shephard's 1966 worldwide male mean, though, when corrected for body size ($\dot{V}O_2max$ ml/kg/m), the value is relatively high. Haulers gave a value of 49.55 ml/kg/m compared to 40.3 in a sample of sedentary Chinese men and 53.0 in "active" Chinese men (Lien and Lai, 1980). The 1980 study used a treadmill protocol which typically produces somewhat higher

values, so we assume hauler values are equivalent to the active men in Lien and Lai's report. Our sense at the time of fieldwork was that the haulers were also healthy and well nourished as a group, and that is supported by values in Table 2.

Bivariate correlation: mean monthly pay

In keeping with the model, we chose measures in expectation that they would predict productivity. Consequently, significant as well as nonsignificant coefficients are both informative. Neither the physiological "gold standard" of work capacity, VO_2max, nor the supervisor's estimation of worker's physical capacity is a significant productivity correlate. However, heart rate/speed, determined in controlled field experiments, shows a significant value and one that is among the strongest predictors in the table. A lower heart rate for speed means that the worker is performing at relatively less physiological strain, and a negative correlation to productivity is consequently predicted. In this case, the value ($r = -0.473$) is based on an N of only 41 due to problems of missing data.

In this group of workers, body size and composition appear to have no role in productivity prediction. However, those with relatively long lower legs are more productive, although the coefficient is low (0.298). Different measures of individual worker health failed to correlate to wages, while the mean health score for all household members did, and alcohol use shows a high coefficient ($r = -0.469$).

Increased carbohydrate intake correlates to higher monthly wages. In the model (Fig. 1) there was an arrow that suggested productivity would be higher as a result of better nutrition. While this paper was under review for publication, one of the reviewers noted "everything in the nutrition literature suggests that the authors have the arrow on the association between carbohydrate consumption and wages reversed." That may be true where food is expensive and undernutrition is the norm, but the Chinese haulers were apparently well nourished, as evident in anthropometric, health, and ethnographic observation. Their wages were high by local standards, and carbohydrates were plentiful and cheap in Beijing. It is axiomatic in exercise physiology that raised carbohydrate intake increases physical performance (McArdle et al., 1996). In a classic cycle ergometry experiment, Bergstrom et al. (1967) fed the same subjects three different dietary regimens. Calories were constant in each, but carbohydrates made up only 5% of the calories at one extreme (high lipid) and 82% at the other (high carbohydrate). On the high carbohydrate diet, subject endurance was *three times greater* than their own performance on low carbohydrates, and physical work output was tied closely to starting muscle glycogen levels. We assume this is also true in Beijing and anywhere else that food intake is not constrained. If carbohydrate intake were caused by productivity in our sample, then we would expect that those with the most money to spend would consume more protein (not supported in Table 2) and would show higher body fat. The correlation coefficient between sum of skinfolds and mean monthly pay in this sample was 0.101, not statistically significant. While we do not reject the possibility that we have the nutrition-production arrow reversed in our model, our ethnographic observation, anthropometric and nutritional data, and reading of the exercise physiology literature suggest otherwise.

We had assumed that capacity to regulate deep body temperature related to higher productivity, whether that means avoiding hyperthermia during high exertion or avoiding loss of core temperature in the cold. That assumption was not supported by the data analysis. Further testing in thermal extremes of hot and cold is needed to explore this question.

Several motivational or behavioral measures showed good prediction of monthly wages. In part this may be due to their constructions, typically integrating a range of contributing factors into a unified score. The ethnographer's motivation estimate was the best single variable predictor of mean monthly wages ($r = 0.518$), but the workers' boss's estimate of their general contribution to the company was also good ($r = 0.449$).

Other measures of the work pattern itself also show promise. Field test data on speed, heart rate variation during the test, and heart rate as a percentage of maximum all

have a voluntary dimension. This is the case because the haulers were instructed to complete the field course at their own chosen pace, and our observations indicate that they did set what was apparently their habitual pace (see Steegmann et al., 1995b). There was nothing to gain from higher speed nor to lose from slower performance. In the series of field tests, neither heart rate as a percent of maximum nor variation in heart rate correlates to pay measures, but speed maintained during this work does (r = .361 to monthly pay).

Bivariate correlations: mean daily pay

The correlation between mean monthly and mean daily pay is 0.795 ($P < .001$). The original justification for using two different measures of work output was the expectation that daily pay should show relatively higher physical and physiological prediction, assuming that once on the job a worker would use his full capacity. But he might not always go to work, advancing the relative importance of social and motivational factors in his overall (monthly) productivity. Correlations to daily pay, as predicted, were moderately higher for heart rate:speed, relative sitting height, and relative lower leg length. It appears that those showing less physiological strain and those with relatively long legs were more productive, and the prediction was stronger for daily than monthly pay. The correlation between heart rate:speed and daily pay (−0.535) is the highest bivariate coefficient in Table 2. Those with better nutrition, health, and motivation were more productive over longer periods.

Multiple regression: mean monthly pay

Several series of backward, stepwise multiple regression tests were run using sets of variables determined by their representation of all model categories (Table 1) and their promise of predictive power (Table 2). The only complexity was that we had complete heart rate:speed data from field experiments on only 41 out of the 45 core sample of men. Even though heart rate:speed has a substantial aerobic capacity component, we decided to start with the larger sample of 45 and use $\dot{V}O_2max$ to estimate aerobic capacity for the first multiple regression test series.

The strongest prediction of mean monthly pay is shown in Table 3. Variables submitted to analysis are listed, including those that were retained (upper left column) and those that dropped out (lower left). In some cases, these variables may not appear a priori to be the strongest predictors, but selection was also based on avoiding high intercorrelation between independent variables. Beta, the standardized regression coefficient, and statistical significance markers indicate the explanatory strength of each variable as it enters, given the variance already explained. Although this statistic assumes nonintercorrelation between independent variables, low correlations have negligible effects. Correlations between these variables are low (Table 3, upper right), and this pattern indicates that multicollinearity is not a problem in the equation (Berry and Feldman, 1985). Further, these coefficients demonstrate that some measures of the various data categories identified in the original model are relatively independent of each other.

Although we assumed from examining the bivariate correlations that the ethnographer's estimation of motivation would enter strongly, it is a broad, integrative measure that reflects a package of behaviors, including alcohol use. In this multiple regression, alcohol use turns out to be a more independent measure, and it displaces the broader motivation marker. Some of the remaining predictiveness of the ethnographic score is also displaced by the boss's score of how much the worker contributed to the business. The ethnographer's and boss's estimates intercorrelate at r = 0.695. The other independent variables are straightforward, with the possible exception of systolic blood pressure. Blood pressure itself has complex causation, but in this case it is not clear whether heredity, stressors, or other factors are operating.

The multiple regression coefficient of 0.818 is higher than those usually attained in productivity studies. Even using the most conservative estimate of variance explained (adjusted R^2), 61.6% of individual work output is predicted. Further, the overall fit of data to the equation, using ANOVA, is F =

12.772 ($P < .001$). This supports our confidence in the general model structure.

During review of this paper for publication, one reader raised a perplexing question. What if nutrition and health status are a *result* of productivity rather than a *cause?* A discussion of our interpretation of nutrition as causal was presented in the preceding section. While we believe that this issue can be clarified in future research, it cannot be answered with this data set. However, we did run a further multiple regression using the same variables as in Table 3 but withdrawing measures of health and nutrition. Table 4 shows that this brings the R to 0.666, with an adjusted R^2 of 0.403. The fit of data to the equation by ANOVA estimation is still strong ($F = 10.908$, $P < .001$).

Because the heart rate for speed variable predicted productivity more strongly than VO2max, we ran a further multiple regression using the same independent variables as in Table 3. The only variable change was substitution of heart rate:speed for $\dot{V}O_2max$, but, due to missing data, the sample was reduced to 41. In this approach (Table 5) the pattern is very similar to that in Table 3. The physiological work capacity estimator (heart rate:speed) still drops out, but not until the fifth iteration. It is of interest that adjusted variance explained is 59.8%, with an overall F value of 12.477—very close to the values seen for the larger sample in Table 3.

Predicting general economic productivity is the objective of this project. While correlations between mean daily pay and independent variables are presented in Table 2, further analysis will not be presented here. It is of interest to work performance questions but less so to longer term productivity.

Structural equation model: mean monthly pay

Figure 2 represents one result from a series of factor analytic structural equation modeling (FASEM) analyses reported elsewhere (Emmer et al., in preparation). The full FASEM approach can be broken down into two nested, simultaneous models (Byrne, 1994). At the center of the overall model is the *structural model*, the hypothesized causal interactions between a set of major theoretical constructs (latent variables, or factors). On the periphery is the *measurement model*, the hypothesized relations between directly measured variables and the latent constructs for which they serve as indicators. Both submodels are proposed by the investigator based on the underlying theory being tested, and both may be modified within the boundaries of that theory during the process of model estimation (Bentler, 1990).

The model in Figure 2 is a nonstandard variation of the full FASEM approach in that the major dependent variable, mean monthly pay, is a directly measured variable rather than a latent construct (for similar examples see Bentler, 1989). This modification was originally made to avoid estimation errors in some models using a latent productivity factor, and the fits of the resulting models were excellent. Since our two productivity measures are simple and largely redundant, this simplification of the model remains consistent with our overall theoretical structure.

The predictor with the strongest influence on mean monthly pay was a behavior latent variable. Alcohol use, smoking, and how well the worker liked his job all load moderately on this general factor. The magnitude of these measurement loadings is indicative of the relative contribution of the latent factor to the observed variation in the measured variables. Variation not attributable to the factor or factors loading on the measured variable is assumed to result from factors outside the scope of the model and is summarized by an error coefficient. The structural coefficients on paths that predict mean monthly pay (.950 from behavior, .260 from physiology, and .172 from error) are analogous to standard regression coefficients. Squaring any of these coefficients gives an estimate of the variance explained by that predictor. In this model, roughly 90% of the variation in mean monthly pay can be attributed to the behavior factor, with 7% and 3% attributed to the physiology factor and error, respectively. Overall fit of the model shown in Figure 2 is extremely good. A summary chi-square statistic of 51.398 (50 df, $P = .419$) strongly supports the fit of the model to the data. In interpreting this value, note that a

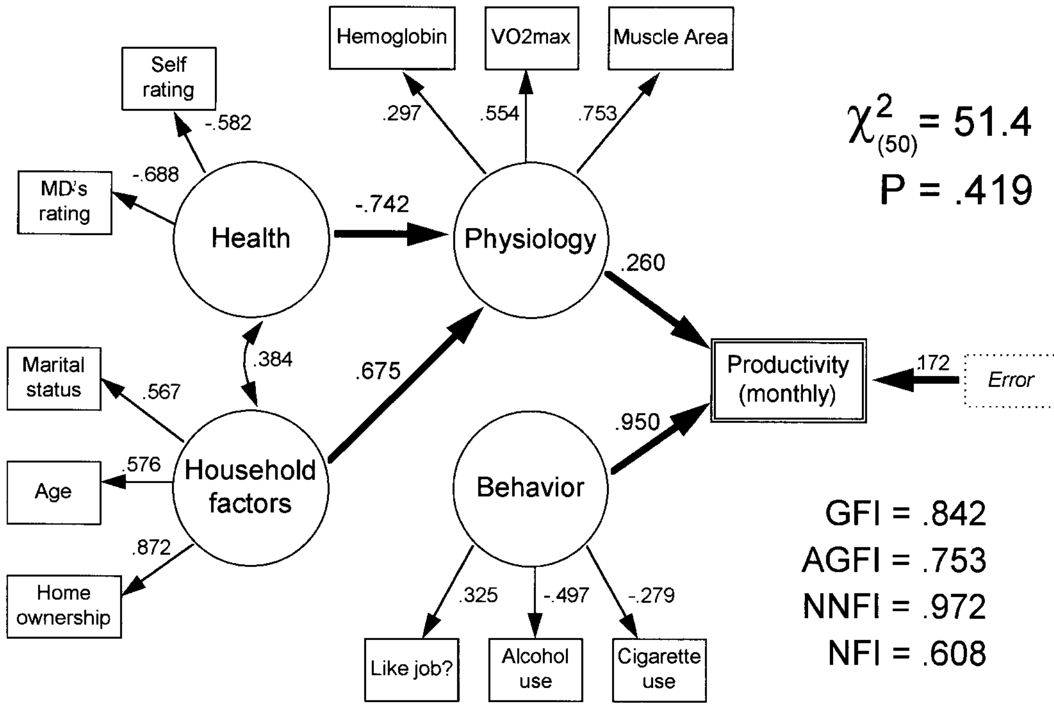

Fig. 2. The best fit of data to a factor analytic structural equation model (FASEM) is illustrated here. Major constructs (latent variables) are contained within the circles. Thick arrows represent structural model paths, thin arrows indicate measurement model paths, and the curved arrow shows a correlation between factors. All coefficients are standardized and measurement errors are not shown. AGFI, adjusted LISREL goodness of fit index; GFI, LISREL goodness of fit index; NFI, Bentler-Bonett normed fit index; NNFI, Bentler-Bonett nonnormed fit index.

high probability indicates acceptance of the null hypothesis that model and data are congruent. Several other standard goodness of fit indices are summarized in Figure 2. None of these indices is associated with a simple test statistic distribution, but all show moderately good overall fit. Further explanation in found in Emmer et al. (in preparation).

DISCUSSION

This research was initiated as a grant application to the National Science Foundation. The model proposed there came from a literature review of factors expected to predict variation in productivity and the combined professional experience of several participants. The senior author was also operating from a cognitive map that expressed the world according to human biology. It was his expectation that all model categories could contribute to explaining productivity variance but that some predictors were likely to be more powerful than others. In order from most influential to least, they were physical work capacity (oxygen uptake; size), cold resistance, health and nutrition, work behavior, and, last, household and social factors (including motivation and self-discipline). The application narrative expressed concern that social and motivational factors could be difficult to measure.

Bivariate correlation results were somewhat surprising. The ethnographer's estimate of how well the worker was functioning was the strongest predictor of monthly wages (r = .518). It is not exactly true to say the weakest category was now to be seen as the strongest, since none of the specific household measures correlated significantly to productivity (Table 2). But this outcome and the fact that alcohol use was a strong predictor were provocative. However, heart rate

for speed (a good measure of physiological work tolerance) was strong, with household health, work speed, and carbohydrate intake also showing a moderate, significant correlation.

One of the glaring absences among the correlates was cold resistance. Parsimony suggests that this was so because body temperature, as a classic homeostatic function, was kept in equilibrium regardless of workload and ambient conditions. It is also possible than the mild Beijing winter of 1991–1992 was a factor, but that is not clear. Neither did size, weight, or body fat correlate to monthly pay. Other productivity studies have gotten mixed results in this model category, some finding morphological correlations and some not.

Using multiple regression we expected that physiological capacity would be sustained as one of the primary predictors, along with the ethnographer's judgment about how well the worker was managing his life. However, we had to reconsider our thinking at this point, if not about the general model structure then at least about which measures were best predictors. In each of the three multiple regressions, alcohol consumption emerged as the single strongest predictor of monthly wages, and the FASEM analysis supported that picture.

There are two categories of explanation for the importance of alcohol use, but they are not mutually exclusive. First, use of alcohol on the job potentially depresses myocardial function and impairs coordination. While research in exercise physiology has not generally found that these are at a level to reduce work capacity (Åstrand and Rodahl, 1986), it is not clear what the effects are on this sample of Chinese haulers. Since we did not test for blood or respiratory alcohol levels of workers in this study, our data do not directly address the physiological aspect of alcohol consumption and work capacity. In fact, we did not anticipate that alcohol use would be so important.

We did get better insight into the social dimensions of alcohol use. It could produce hangovers, interpersonal conflict, failure of discipline, and, in the end, lost work time. In one case that occurred while we were there, two workers got into an after-hours fight, evidently when they were intoxicated. One suffered injuries sufficient to cause missed work, and the other, a senior, respected member of the unit, suffered loss of respect and status. The effects of alcohol use need not be physiological or even on the job in order to reduce work output. However, it must be stressed that, in our perception, workers in this group were generally only moderate drinkers. Determining more precisely how much alcohol is consumed and how alcohol use may relate to physical performance and other factors such as social networks, living conditions, and self-discipline is of considerable interest. From the worker's perception, alcohol use may have some benefits in this demanding occupation.

Because alcohol was a strong predictor, we were curious to see whether other variables would still explain a substantial portion of productivity variance without the overriding influence of the alcohol use variable. Multiple regression of the same variables shown in Table 3 but without alcohol reduced the R value to .690 and the adjusted R^2 to .437 ($F = 12.394$). Only the boss's estimation of overall contribution, household health, and carbohydrate consumption remained in regression on mean monthly pay. This implies that alcohol use is not just a surrogate but is also very important in itself.

The second strongest predictor of monthly pay in the Table 3 regression is the work supervisor's estimate of how much the worker contributed to the general enterprise. This was a qualitative judgment by an experienced manager who worked with the men every day. It correlates only to blood pressure ($r = .305$) among the other variables entered into the regression, and that supports our speculation that blood pressure is partly a motivation indicator, as is the boss's evaluation. That a supervisor's rating should be treated as an independent variable is a judgment on our part. It may be predictive in that it identifies a package of traits that are at the core of worker effectiveness. However, we recognize that the boss's estimate is partly a consequence of worker output.

Household health and carbohydrate intake were discussed in the preceding sec-

tion. It is difficult to see how the poor health of others would effect a hauler's work output unless it decreased the support or increased the demand on the worker—functions of a social network. Specific mechanisms by which this operates are probably a part of household dynamics. It is probably not a physical phenomenon, since the health of the worker himself has only marginal effects on his work output, as reflected in bivariate correlations and the weak showing in multiple regression and FASEM analyses. We are suggesting that the positive effect of carbohydrate intake on work capacity is a consequence of more energy being available in muscle tissue.

Increased resting blood pressure has multiple origins, but why it should be associated with more work output is not clear. Typically, those most fit aerobically have relatively low blood pressures (McArdle et al., 1996). In this group of well-conditioned haulers, there was no blood pressure to $\dot{V}O_2max$ correlation, probably because they had to attain a threshold of fitness to do the work. One possibility is that blood pressure is higher in workers with more self-demanding personalities and that it has no direct biological effect on work performance. That is, it may be acting here as an indirect marker of self-discipline or ambition.

Two categories of variables in the original model, physical size/body composition and aerobic capacity ($\dot{V}O_2max$), did not enter in the multiple regression. If physical size had been important in enhancing productivity but fell out of the multiple regression due to covariance with stronger variables, it would still have appeared on the list of simple correlations, but it did not. Consequently, we are confident in our judgment that body size was not important. This may have to do with the biomechanics of cycle hauling or may be intrinsically unimportant in this pattern of work. Body characteristics had some role in productivity among cane cutters (Morrison and Blake, 1974; Spurr et al., 1977) but not among lumberjacks (Hansson, 1965) or tea plantation laborers (Roy, 1995). Aerobic capacity is probably more important in some occupations than others.

A third measure, the ethnographer's estimation of overall motivation, was a very strong correlate with monthly pay but dropped out of the multiple regression (Table 3). We assume that this occurs because the measure was very efficient. That is, it incorporated a range of indications of work ability. However, some of those were measured by other variables in the equation.

Structural equation model

In its major dimensions, the FASEM model (Fig. 2) agrees with results of the bivariate correlation and multiple regression findings. Productivity of cycle haulers is not strongly driven by physical or physiological factors. We assume that this is so partly because this occupation, though demanding physically, gives the worker unusual autonomy to regulate the pace of work and even how much work one may choose to do on any given day. Consequently, discipline counts for a lot in compensating for lack of sheer power, but it is probably more complex than that. If someone joins a hauler unit and finds the work too taxing, the person quits and gets into another occupation. Those who remain can at least turn in a consistent performance. All of these factors may act to reduce the importance of biological work capacity. In a closely supervised industrial job such as steelworking or fabrication, physical capacity may be more important.

The second distinction in this model is that physiological capacity is predicted quite strongly by both health and household latent variables, and the two have some mutual interaction. There is a tendency for older married men who own houses to be stronger physiologically. Good household and worker health make a parallel prediction. Consequently, these three latent variables (household, health, and physiological capacity) represent a biobehavioral package that might be called *well being*, but its influence on productivity is quite modest. That was not predicted by the original model and stands as a result of empirical testing.

SUMMARY AND CONCLUSIONS

This research tested a model that predicts human economic work output (average monthly wages). We assumed that physiological and morphological work capacity, cold resistance, health, nutrition, work be-

havior, and social factors all affect work output with decreasing power in the approximate order listed. Our results produced both agreements and disagreements with the original construct, as follows.

1. Alcohol use was the strongest predictor, showing a negative relationship to wages in multivariate equations. Whether that function was primarily physiological or social in action is ambiguous, but neither was tested directly. Our observation of cycle haulers' actual work and other behaviors left the impression that social factors were important. This interpretation is supported by evaluations from the workers' boss about how well individuals contributed to the business—another strong multivariate predictor that could be called *professionalism*. In bivariate correlation analysis, a similar assessment generated by an American ethnographer (Hewner) and Chinese physician (Sun) was the most powerful single predictor of monthly wages.
2. The summary household health rating, including all members of each worker's household, also entered multivariate analyses, with moderate strength. Since productivity declines as does household health, this may represent a drain on the hauler's time and energy—a negative consequence of social obligations. While we may instead be observing a *consequence* of lower productivity, the model needs further testing on this issue. Neither is it clear why resting systolic blood pressure is higher in more productive workers, though we speculate that this may be a marker of self-imposed discipline. On the other hand, the relationship between higher carbohydrate intake and higher earnings is interpreted in the framework used by work physiologists. Readily available energy consumption means that muscle tissue has more energy available for physical work. The health of the individual worker showed only marginal power to explain wages—possibly relating to lost work time.
3. An interesting aspect of the way independent variables behaved in the multiple regressions is that they were essentially unrelated to each other, and each made a sizable contribution to explained variance. Consequently, the regression shown in Table 3 could explain 61.6% of the monthly wage variance, and this adjusted R^2 is a conservative estimate suited to the large number of independent variables entered. If our assumptions about predictive directions in the model are correct, this is a very strong result.
4. We were somewhat surprised at some of the variables that were expected to be predictors but were not, particularly measures of morphological and physiological work capacity. They failed to stay in any of the multiple regressions and made only peripheral showing in the LISREL model. Our interpretation is that the management of work pacing, controlled largely by the individual haulers, compensated for lack of physical capacity. However, it should also be emphasized that all of the haulers were above some minimal threshold of strength and aerobic power or they would not have been in this occupation. Haulers represent a self-selected sample. We also hold reservations about how maximum the $\dot{V}O_2max$ measure was in a few of the subjects. This could reduce the explanatory power of physiological measures due to experimental artifact. Finally, resistance to body heating or cooling, expected to make a strong showing, was an even weaker category than physical work capacity.
5. The importance of physiological and morphological mechanisms in human adaptation is a major operational assumption in anthropological human biology. Over the last 40 years, we have done much research which has tested and supported that view (e.g., Damon, 1975; Little and Haas, 1989; Mascie-Taylor and Bogin, 1995). However, here we have examined a factor of unquestionable centrality to human well being: individual economic productivity. While urban laborers may not represent humankind at large, they do constitute a major sector of human economic activity. In the investigation reported here, morphology and physiology were not strong predictors, although others were. Put another way, this is a

case in which a primary human adaptation, economic output, was predictable but less so than anticipated through the expected channels. However, this is not incompatible with a growing body of applied and theoretical literature (Kaplan, 1996; Shephard and Rode, 1996; Smith and Winterhalder, 1992). In a sense, we are not so much looking at the already established links between socioeconomic status and well being but rather assessing factors that might produce socioeconomic status itself. Future testing of this model should be done on a work force that samples the entire range of workers in a natural work setting.

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LITERATURE CITED

Åstrand P-O, and Rodahl K (1986) Textbook of Work Physiology: Physiological Bases of Exercise, 3rd ed. New York: McGraw-Hill.

Bentler PM (1989) EQS: Structural Equations Program Manual. Los Angeles: BMDP Statistical Software.

Bentler PM (1990) Latent variable structural models for separating specific from general effects. In L Sechrest, E Perrin, and J Bunker (eds.): Research Methodology: Strengthening Causal Interpretations of Non-Experimental Data. (PHS) 90-3454. Springfield: NITS, pp. 61–80.

Bergstrom J, Hermansen L, Hartman E, and Slatkin B (1967) Diet, muscle glycogen and physical performance. Acta Scand. Physiol. *71:*140–150.

Bernard HR (1994) Research Methods in Anthropology: Qualitative and Quantitative Approaches, 2nd ed. Thousand Oaks: Sage.

Berry WD, and Feldman S (1985) Multiple Regression in Practice. Beverly Hills: Sage.

Borg GAV (1982) Psychosocial bases of perceived exertion. Med. Sci. Sports Exerc. *14:*377–381.

Borgatta EF, and Bohrnstedt GW (1981) Level of measurement all over again. In GW Bohrnstedt and EF Borgatta (eds.): Social Science Measurement: Current Issues. Beverly Hills: Sage, pp. 23–37.

Byrne BM (1994) Structural Equation Modeling With EQS and EQS/Windows. Thousand Oaks: Sage.

Collins KJ, and Roberts DF (eds.) (1988) Capacity for Work in the Tropics. New York: Cambridge.

Consolazio CF, Johnson RE, and Pecora LJ (1963) Physiological Measurements of Metabolic Functions in Man. New York: McGraw-Hill.

Damon A (ed.) (1975) Physiological Anthropology. New York: Oxford.

Emmer DW, Steegmann AT Jr, and Hewner SJ (in preparation) Structural equation modeling of Chinese worker productivity.

FAO (1972) Food Composition Table for Use in East Asia. Rome: FAO.

Frisancho AR (1990) Anthropometric Standards for the Assessment of Growth and Nutritional Status. Ann Arbor: University of Michigan Press.

Hansson JE (1965) The relationship between individual characteristics of the worker and output of logging operations. Studia Forest Suecia *29:*68–77.

Hewner SJ, and Sun W (1995) Worker motivation and productivity in Chinese (Beijing) tricycle haulers: Integrating social and biological variables. Am. J. Hum. Biol. *7:*21–32.

Human Dimensions of Chinese Adults (1988) People's Republic of China National Standard GB 10000-88, National Bureau of Technology Supervision. Beijing (in Chinese).

Kaplan H (1996) A theory of fertility and parental investment in traditional and modern societies. Yrbk. Phys. Anthropol. *39:*91–135.

Lien IN, and Lai JS (1980) Endurance capacity and exercise response in young Chinese adults. J. Formosan Med. Assn. *79:*1109–1121.

Likert R (1932) A technique for the measurement of attitudes. Archives Psych., Series 140 (1932–1933), *22:*5–55.

Little MA, and Haas JD (eds.) (1989) Human Population Biology: A Transdisciplinary Science. New York: Oxford.

Lohman TG (1981) Skinfolds and body density and their relation to body fatness: A review. Hum. Biol. *53:*181–225.

Lohman TG, Roche AF, and Martorell R (eds.) (1988) Anthropometric Standardization Reference Manual. Champaign: Human Kinetics Books.

Mascie-Taylor CGN, and Bogin B (eds.) (1995) Human Variability and Plasticity. Cambridge: Cambridge University Press.

McArdle WD, Katch FI, and Katch VL (1991) Exercise Physiology: Energy, Nutrition, and Human Performance, 3rd ed. Philadelphia: Lea and Febiger.

McArdle WD, Katch FI, and Katch VL (1996) Exercise Physiology: Energy, Nutrition, and Human Performance, 4th ed. Baltimore: Williams and Wilkins.

Morrison JF, and Blake GTW (1974) Physiological observations in cane cutters. Eur. J. Appl. Physiol. *33:*247–254.

Pedhazur EJ (1982) Multiple Regression in Behavioral Research, 2nd ed. Fort Worth: Holt, Reinhart and Winston.

Roy SK (1995) Comparative study of physiological and anthropometric characteristics of high and low productivity workers in northern West Bengal, India. Am. J. Hum. Biol. *7:*693–699.

Shephard RJ (1966) World standards of cardiorespiratory performance. Arch. Environ. Health *13:*664–672.

Shephard RJ, and Rode A (1996) The Health Consequences of "Modernization": Evidence from Circumpolar Peoples. Cambridge: Cambridge University Press.

Smith EA, and Winterhalder B (eds.) (1992) Evolutionary Ecology and Human Behavior. New York: Aldine de Gruyter.

Spurr GB, Barac-Nieto M, and Maksud MG (1977) Productivity and maximum oxygen consumption in sugarcane cutters. Am. J. Clin. Nutr. *30:*316–321.

Steegmann AT Jr, Li TL, Hewner SJ, Emmer DW, Zhang X, and Leonard WR (1995a) China Productivity Project: General description and analysis of productivity. Am. J. Hum. Biol. *7:*7–19.

Steegmann AT Jr, Li TL, Emmer DW, Hewner SJ, Zhang X, and Liu Z (1995b) Work performance of Chinese cycle haulers: Controlled field experiments in normal work conditions. Am. J. Phys. Anthropol. *97:*147–160.